TABLE 18.—*Seasonal distribution of transpiration. Höhnel's 1879 experiments.*

Tree.	Per cent of seasonal total, June–September.			
	June.	July.	August.	September.
Ash	23.0	28.0	29.4	18.9
Birch	*19.9*	28.6	36.8	*14.5*
Beech	24.5	29.0	30.0	16.6
Hornbeam or ironwood	16.4	28.8	32.9	21.7
Elm (field)	24.4	26.4	29.9	19.0
Oak ("Stiel" and "Trauben")	19.4	22.8	30.5	27.0
Oak ("Zerr")	17.9	25.2	36.7	20.5
Spruce	24.1	31.1	29.0	16.0
Fir	20.0	27.5	30.8	21.5
Pine (*Scotch white*)	20.0	27.5	28.1	23.8
Pine (black Austrian)	23.5	24.8	26.9	18.3
Average	21.2	27.2	31.0	19.8
Höhnel's measured evaporation, 1879, per cent	27.2	25.9	26.5	20.5

Evaporation from the soil surface can also be approximately determined. The total water losses are known for many areas from a comparison of the measured run-off and precipitation.

The leaf-weight ratios used in Table 15 are those for the larger trees where available. Values for larger trees were used instead of an average of those for large and small trees, because determinations of transpiration losses from larger trees are those most generally described. Comparing the leaf-weight ratios, column 9 of Tables 8 and 9, for large and small trees, it will be found that the ratios for young trees are generally, though not always, considerably the larger. In other words, trees of less than 10 years of age have more leaf weight per unit of diameter times height than mature trees. The method of calculation here used, based on leaf-weight data for mature trees, apparently leads to too small values of estimated transpiration when applied to very young trees. No certain method of correcting for this factor is at present available. In view of the fact that the thickness of the leaf layer in the tree crown becomes more nearly constant after the tree has reached a moderate size and the crown begins to have a core or hollow center, it may be fairly presumed that this error is not involved except in comparatively young trees.

A determination of the ratio $\frac{\text{dry leaf weight}}{\text{diameter} \times \text{height}}$ was made in general for only one large tree of each kind. Better results would no doubt be obtained by averaging a large number of trees of the same size and species. Furthermore, it is desirable that such investigations should be carried out for various sizes or ages of trees of the same species. In spite of the necessity of cutting down many trees and the great amount of labor involved in a leafage determination, even for a single tree, it is to be hoped that extensive data along the lines above suggested may be obtained in the near future.

Forest transpiration is of course limited by available water supply derived from precipitation. However, this is automatically taken into account in a large measure, since the type of forest which will grow on a given area and the size attained by the trees is conditioned by rainfall and other environmental factors. While a transpiration loss of 25 inches or more may occur in a full-stocked mature beech forest under favorable conditions, the existence of such a forest stand is proof positive of rainfall sufficiently abundant to support it and to provide the corresponding transpiration and other water losses. In another region with materially lower rainfall an equally dense stand of beech would not be found.

The seasonal transpiration losses can be distributed throughout the different months by taking the transpiration for each month as proportional to the ratio of the evaporative capacity for the given month to the total for the season. The relation between the two as determined by Höhnel's experiments is shown for the growing season, June-September, in Table 18. Separate calcultaions should be made for the growing and dormant seasons because the ratio of transpiration to evaporation rate is higher during the growing than during the dormant forest season. The months of May and October are transition periods for which the ratios of transpiration to evaporation are about midway between their winter and summer values.[6]

[6] Other references on this subject are:
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NOTES ON THE 1922 FREEZE IN SOUTHERN CALIFORNIA.

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It is safe to say that a winter never passes without the occurrence of frost somewhere in the citrus-growing sections of southern California. During many winters, however, the temperature in these districts does not fall low enough to damage citrus fruits. In other winters the damage is slight and is confined to samll areas in the colder localities. In mild winters the light frosts are looked upon by the fruit growers as beneficial, serving to improve the color and flavor of the navel orange.

At intervals of about 10 years, on the average, general heavy freezes have visited the citrus districts, damaging the fruit and trees to the extent of many millions of dollars. These "freezes" partake more of the nature of a cold wave than a frost; in fact, the freeze is a combination of cold wave and frost. A wave of low temperatures advances southward from the Canadian border, on the southern and southwestern borders of a well-developed high-pressure area. A strong, cold northerly wind prevents the normal rise in temperature during the day. When this wind dies out in the evening, the temperature falls with startling rapidity, owning to the low humidity which prevails in southern California under these conditions of pressure distribution.

Strong temperature inversions develop on hillsides and slopes in the citrus districts on calm, frosty nights, but during a freeze differences in temperature between hillside and valley floor are usually slight. The most important factor in limiting or preventing damage during a freeze is the occurrence of a steady wind which continues to blow throughout the night.

Temperatures low enough to damage seriously citrus fruits over a considerable area in southern California occurred in 1913, 1918, and 1922. Freezes occuured in 1913 and 1922, and a serious frost occurred in 1918. In 1913 and 1922 orchards on the higher ground suffered as much damage, in general, as those on the low ground, while in 1918 orchards on the slopes escaped with little or no damage. Some remarkable differences between minimum temperatures at the bases and on the slopes of hills were recorded during the severe frosts of 1918. On one of the colder nights of this season, a minimum temperature of 21° F. was recorded at the base of a hill, while the minimum temperature at a point 225 feet above, on the slope, was 49° F. On the coldest night in 1922 the difference in minimum temperature between the same two stations was 9° F., the minimum at the base being 18° F. and that at the 225-foot station 27° F. These two stations were about one-half mile apart in a straight line.

THE 1922 FREEZE.

As a general rule, the growth of citrus trees is checked in the fall by cool weather, and the trees remain in a semi-dormant condition during the winter. While in this condition they are quite resistant to cold. November and December, 1921, and the first half of January, 1922, were unusually free even from light frosts. Mild, rainy weather prevailed during this period, and orange and lemon trees put on much new and succulent growth, making them especially susceptible to damage by low temperature. No serious, widespread damage by low temperature had occurred later than January 15 within the memory of the fruit growers, and this, together with the exceptional mildness of the season up to that time, had thrown them off their guard. Many growers with full orchard-heating equipment were unprepared for the cold that followed.

On the morning of January 18, 1922, a large HIGH, over the extreme northwest, was showing increased intensity, and was pushing southward in the wake of a well-developed LOW, central over Arizona and New Mexico. Temperatures were falling rapidly over Washington, Oregon, and Nevada, and had fallen slightly in California. The evening weather map of the 18th showed a great fall in temperature over northern California, with temperatures below freezing at 5 p. m. in the upper Sacramento Valley. On the morning of the 19th, the HIGH had increased in intensity and had moved farther south, causing 24-hour temperature falls of from 6 to 18° F. in northern California, and 22 to 24° F. in Nevada. At 5 a. m. Pacific time the temperature was 32° F. or lower throughout northern California, including the coast stations. At the same time the temperature was −14° F. at Winnemucca, and −8° F. at Tonopah, Nev. The evening weather map of the same date showed the positions of the HIGH and LOW practically unchanged since morning, and current temperatures but little lower than on the previous night.

During the night of the 19th–20th, the HIGH increased in size and pushed southward, and on the morning of the 20th the LOW had filled up and disappeared. This night was the beginning of the freeze in southern California, which continued in some localities for five consecutive nights.

LOCAL ASPECTS OF THE FREEZE.

In the great valley of southern California (see fig. 1) the sky was overcast on January 19, with a disagreeably cool northeasterly wind. At the 4:40 p. m. observation at Pomona the temperature of the dew point was 12° F. At that time the weather was clear at Los Angeles, 30 miles to the westward, and a little later the sky cleared at Redlands, about 30 miles east of Pomona, but cloudiness continued at Pomona until about 6:30 p. m. Throughout the great valley the temperature fell rapidly as soon as the sky cleared. Because of the low dew point the rapid fall was not checked until about midnight, when the temperature had reached 21°, and then only because of light, intermittent puffs of wind.

In probably 90 per cent of the winter frosts in southern California the evening dew point is above 28° F. On such nights there is a rapid temperature fall in the early evening, until the dew point is reached, after which there is a slow fall, or a stationary temperature for an hour or longer. For this reason fruit growers who could not be reached with a warning, knowing nothing of the low dew point, felt no concern over the rapidly falling temperature. Many growers who had very complete frost-fighting equipment lost their crops through failure to begin firing early enough in the evening on January 19.

Throughout the period of the freeze there was a rather strong barometric pressure gradient from north to south. This was especially true of the night of the 19th–20th, which was the coldest night of the freeze in the sections immediately south of the San Gabriel Mountains. On the summit of Mount Wilson, elevation 5,850 feet, the average wind velocity during the period from 7 p. m. on the 19th to 7 a. m. on the 20th was 23 miles per hour. In valleys extending north and south this wind was unobstructed, and continued to blow all night, practically without cessation, preventing the development of temperature inversions, and maintaining the temperature at a point high enough to prevent serious damage.

The San Gabriel Mountains, which extend in an east-west direction on the north side of the San Gabriel Valley, acted as a very effective windbreak, and in the northern half of this valley only light, shifting breezes were felt, with long intervals of practically complete calm. This produced an almost ideal condition for a rapid temperature fall and unusually low temperatures. Minimum temperatures as low as 18° F. were registered in standard Weather Bureau instrument shelters in orange groves in the San Gabriel Valley on this night. Figure 1 shows the location of temperature stations by numbers and Table 1 shows minimum temperatures at all stations in operation, for the two coldest nights of the freeze.

TABLE 1.—*Minimum temperatures in southern California on nights of January 19–20 and 20–21, 1922.*

(Locations of stations shown in fig. 1.)

Station number.	January—		Station number.	January—	
	19–20	20–21		19–20	20–21
	°F.	*°F.*		*°F.*	*°F.*
1	25	29	30	26	24
2	22	25	31	29	34
3	21	24	32	27	27
4 [1]	15	23	33	25	27
5	32	31	34	30	24
6	25	23	35	24	25
7	27	25	36	23	26
8	29	31	37	25	22
9	23	24	38	27	34
10	18	21	39	23	20
11	22	22	40	23	23
12	18	18	41	22	23
13	27	34	42	25	19
14	20	21	43	24	23
15	23	23	44	24	22
16	20	24	45	28	26
17	21	24	46	26	31
18	24	23	47 [1]	3	10
19	26	23	48 [1]	7	13
20	24	25	49	21	22
21	31	28	50	21	23
22	30	33	51	19	27
23	24	24	52	20	23
24	23	24	53	19	20
25	25	19	54	20	23
26	28	22	55	20	23
27	23	25	56	20	23
28	22	24	57	22	25
29	29	24	58 [1]	8	13

[1] These stations located near the summit of the mountain ranges on the north side of the valley.

NOTE.—At stations located in the line of the strong surface wind, as indicated by the arrows in Figure 1, the temperature fluctuated up and down all night, and the duration of the minimum temperature was very short, in some cases only 2 or 3 minutes. At other stations, the fall in temperature was steady all night, with duration below the danger point for citrus fruits of 14 to 15 hours in extreme cases.

FIG. 4.—Navel orange grove showing excellent condition of trees and fruit, which were protected with forty 7-gallon Scheu high-stack cast-iron oil orchard heaters to the acre.

FIG. 2.—Bark of bearing lemon tree split by low temperatures

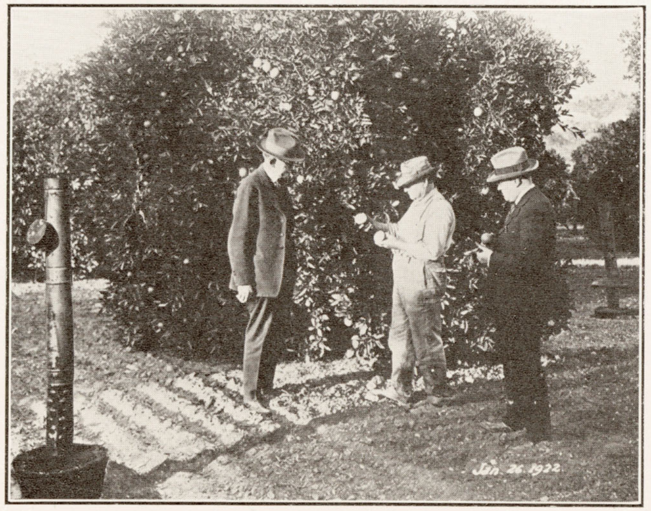

FIG. 5.—View in orange grove in which only outside fruit or on border rows of trees showed damage from frost. The firing in this grove was poorly done, and there is no doubt that there would have been no damage had the work been properly done.

FIG. 3.—Navel orange tree in an unprotected grove. Practically entire crop on the ground and all the fruit showed frost damage. Note curled and dried leaves on outside of tree.

FIG. 6.—General view of an unprotected grove with damaged trees.

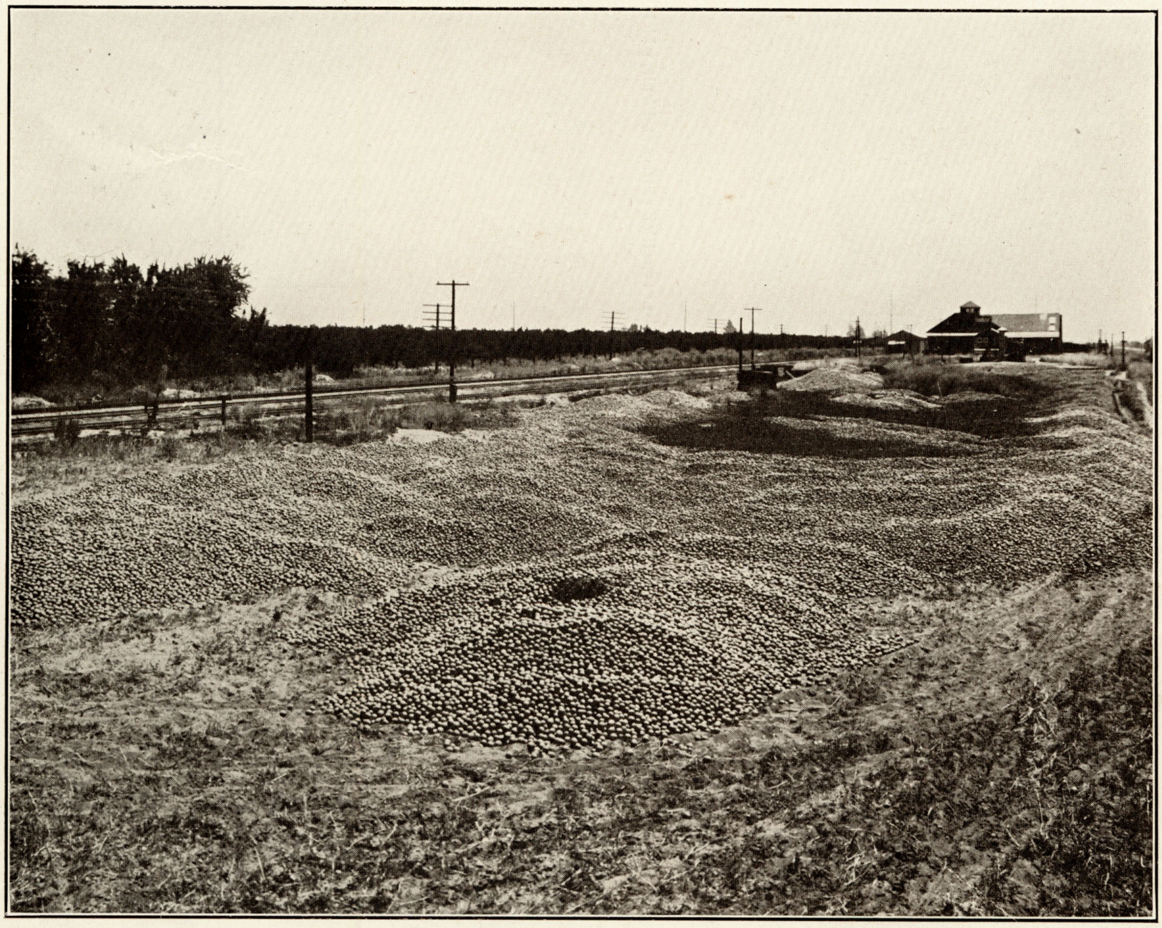

FIG. 7.—Frozen orange dump, near Ontario, Calif., June 17, 1922.

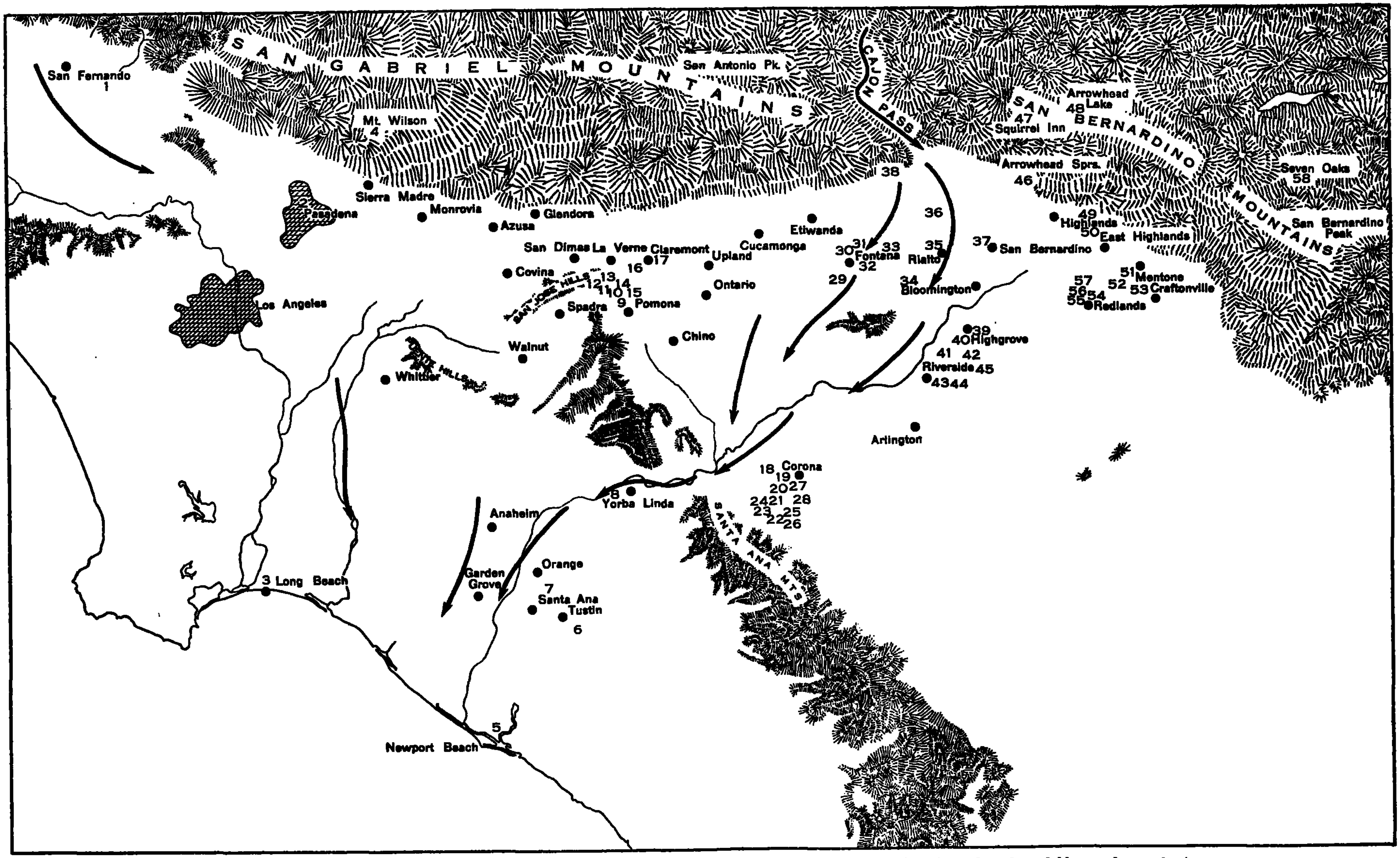

FIG. 1.—Sketch map of the Great Valley of Southern California and surrounding country showing the location of all stations where dependable records were kept. Numbers refer to stations, minimum temperatures at which are given in Table 1.

Farther east, Cajon Pass allowed the wind to flow through from the Mojave Desert, preventing serious damage in the citrus districts to the southward. Ample proof that the wind was instrumental in preventing damage in the favored localities on this night is found in the rapid fluctuations in temperature which are shown on thermograph records. During momentary lulls in the velocity of the wind the temperature fell with startling rapidity, only to rise again when the wind again freshened. The north wind which poured through Cajon Pass was confined to a rather narrow belt, which shifted slightly in an easterly and westerly direction from time to time.

Familiarity with the general pressure conditions, together with information early in the evening that the wind was rapidly subsiding in the northern foot hill sections of the San Gabriel Valley, made it possible to forecast a direct reversal of the usual temperature conditions on frosty nights in that district. A warning was sent out that the temperature would fall earlier and more rapidly on the higher ground adjoining the foothills than on the floor of the valley. This warning was fully verified.

On the nights of the freeze subsequent to that of the 19th–20th the wind velocity was not such an important factor generally. However, there was enough wind on all nights in the valleys extending north and south to prevent great damage, and the winds through Cajon Pass were strong enough on all nights to show their effects on the temperature in the districts lying to the south and west.

As might be expected in a district with such broken topography, there was a great variation in the amount of damage to fruit in different orchards, often within short distances. Much of this variation was due to differences in elevation, but in some districts wind played a more important part than topography in regulating the temperature during the cold nights. In general, districts without obstructions for several miles to the northward which would break the force of the wind escaped with comparatively little damage. On the other hand, in at least one district almost within view of the Pacific Ocean, but sheltered on the north and east by high hills, temperatures were low enough to split the bark on the trunks of bearing lemon trees. (Fig. 2.)

DAMAGE CAUSED BY 1922 FREEZE.

Damage to fruit throughout the citrus sections was enormous in the aggregate. In hundreds of groves the entire crop was lost. Unusually high prices were received for the marketable portion of the crop, so that the total returns did not correctly indicate the amount of damage. California Fruit Growers' Exchange officials state that 53 per cent of a normal crop of oranges brought 90 per cent of the average returns. The gross returns for the 1921 citrus crop f. o. b. California were $83,537,344. The 1922 crop was larger than the 1921 crop, and the fruit was of better quality, prior to the freeze. Including fruit marketed prior to the freeze, the total gross returns for the 1922 crop were $71,366,464. Using these figures as a basis, this would indicate a loss to the industry of more than $12,000,000. If this $12,000,000 had been equitably distributed among all the growers of citrus fruits, the strain would not have been great. As a matter of fact, however, growers who protected their crops, and those located where the cold was not so severe, received unusually large returns, while many others received nothing. The loss to the country at large, based on the delivered value of the crop, was $32,437,574. Damage to trees was extensive, but the loss from this source is difficult to estimate. (Fig. 3.)

In an application made by transcontinental railroads to the Interstate Commerce Commission for permission to grant a reduction from $2.33 to $1 per hundredweight in the freight rate on orchard heaters from the factory at Toledo, Ohio, to southern California, the railroads pointed out that the 1922 freeze had reduced the size of the crop shipped by nearly 20,000 cars, or about $10,000,000 gross revenue. It is estimated that the reduction, which was granted, saved about $40,000 in freight charges on the year's supply of new heaters. The railroads were willing to donate this amount to encourage the use of orchard heaters in southern California.

ORCHARD HEATING.

The freeze had one redeeming feature, in that it demonstrated conclusively that citrus trees and fruit in southern California can be saved from damage during extreme conditions of low temperature, provided the frost-fighting equipment is adequate and is efficiently handled. Numerous proofs of this fact were obtainable after the freeze, but only one will be mentioned here, since in this case the writer was present on the ground during all the cold nights and carefully checked all the data. (See figs. 4–7.)

About two months prior to the freeze two temperature stations had been established for the purpose of determining the amount of temperature rise that could be obtained with a given number of orchard heaters to the acre. One station was placed in an orchard equipped with fifty 7-gallon oil-burning orchard heaters to the acre. The other was placed in an adjoining orange grove which was not equipped with heaters, about one-fourth mile distant. Minimum temperatures at the station in the fired orchard were consistently about 1° F. higher than at the check station on nights with light frosts, but on the night of the 19th-20th there was little temperature inversion and temperatures at nearly all stations in the same general locality ran about the same. Temperatures at these two stations were practically identical on the evening of the 19th, up to the time the heaters were lighted.

The actual temperature records secured at these two stations, using special 29-hour thermographs, carefully checked at intervals of about 15 minutes throughout most of the night, are shown herewith. (Fig. 8.) The temperature station in the fired grove was placed as far from any orchard heater as possible.

Due to the mild season and the late date at which the freeze began, the owner of the fired orchard had allowed the oil supply in his storage tanks to become depleted, so that he had no oil available for refilling his heaters when they burned out in the morning, at the time the outside temperature was at about its lowest point. During the three or four coldest hours of the night he was left with only one-half his heaters burning. Notwithstanding this fact, only 4.5 per cent of the fruit in the fired grove proved to be unmarketable because of frost damage. The trees were not injured, and many fresh, undamaged orange buds and blossoms were found on the following day. In the unfired orchard, where the check temperature station was located, the crop was a total loss, the trees were defoliated, and there was some cracking of the bark on large branches.

The numerous examples of the value of orchard heating served to increase the interest in frost protection. Heaters were purchased to equip thousands of acres of